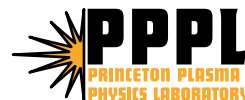# THE NATIONAL FUSION COLLABORATORY

D.P. Schissel, A. Finkelstein, I.T. Foster, T.W. Fredian, M.J. Greenwald, C.D. Hansen, C.R. Johnson, S.A. Klasky, K. Li, D.C. McCune, Q. Peng, R. Stevens, M.R. Thompson

http://www.fusiongrid.org

*NIMROD simulated pressure stored
in MDSplus and visualized with IDL*

158-01 jy

OUTLINE OF PRESENTATION

- **Fusion is nature's fundamental power source**
  - Fusion is the power source of the sun and all the stars in the universe
  - Rich area of worldwide scientific research

- **Benefits of the National Fusion Collaboratory**
  - Advance scientific understanding and innovation in fusion research
  - Deployment of innovative software not hardware

- **Deliverables**
  - Centered around demonstrations to Fusion & CSET community
  - Our fusion customers are the experimental & theoretical communities

158–01

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A NEW THREE YEAR PROJECT HAS STARTED TO CREATE A NATIONAL FUSION COLLABORATORY

- **The fusion Collaboratory represents a fundamental paradigm shift for the fusion community**

- **All data, analysis and simulation codes, and visualization tools will be thought of as network services**

- **The use of resources (data, codes, visualization tools) is separated from their implementation freeing the researcher from the need to know, in detail, how resources are implemented**
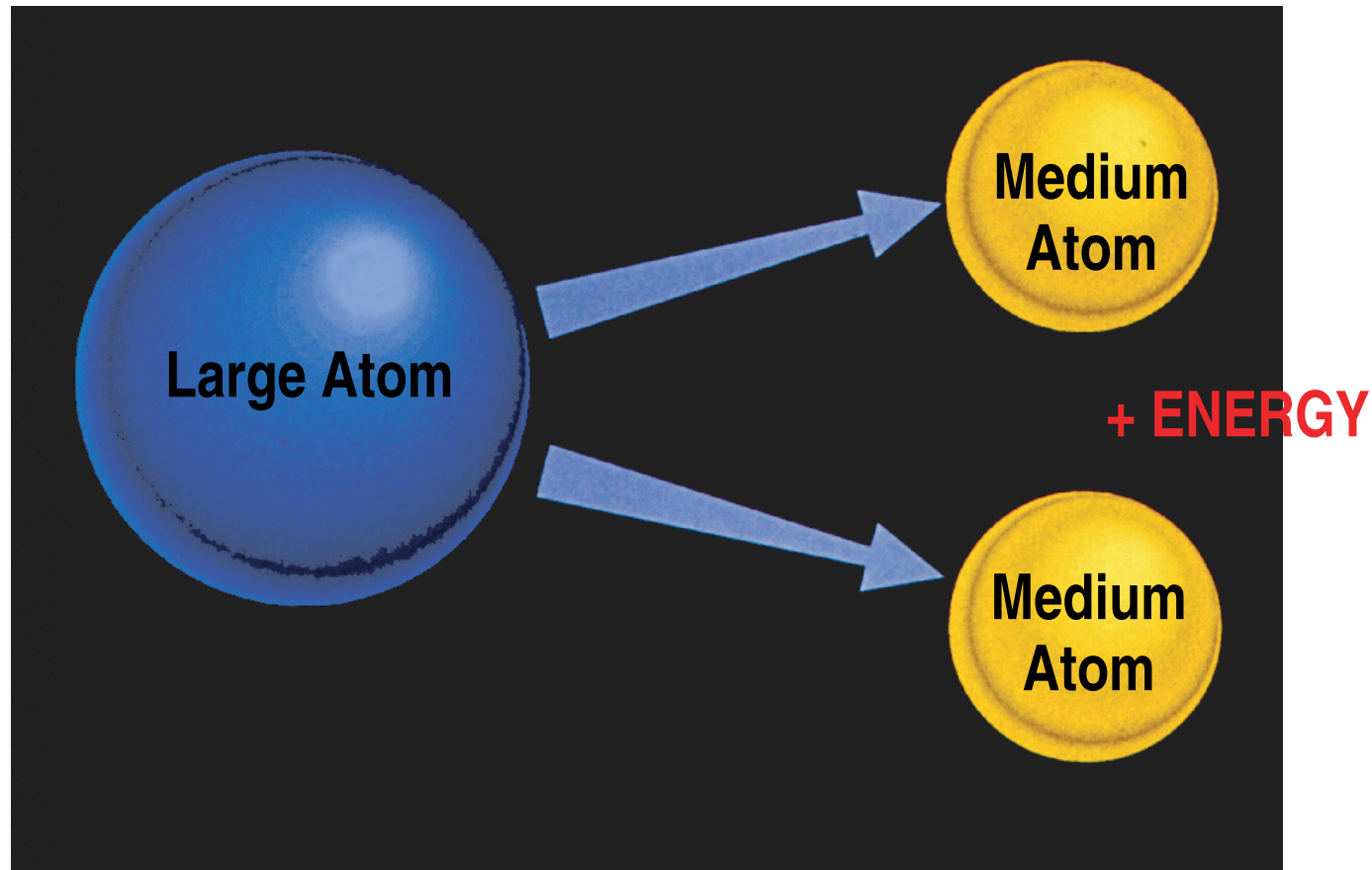
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FUSION IS NATURE'S FUNDAMENTAL ENERGY SOURCE: THE POWER SOURCE OF OUR SUN AND ALL THE STARS
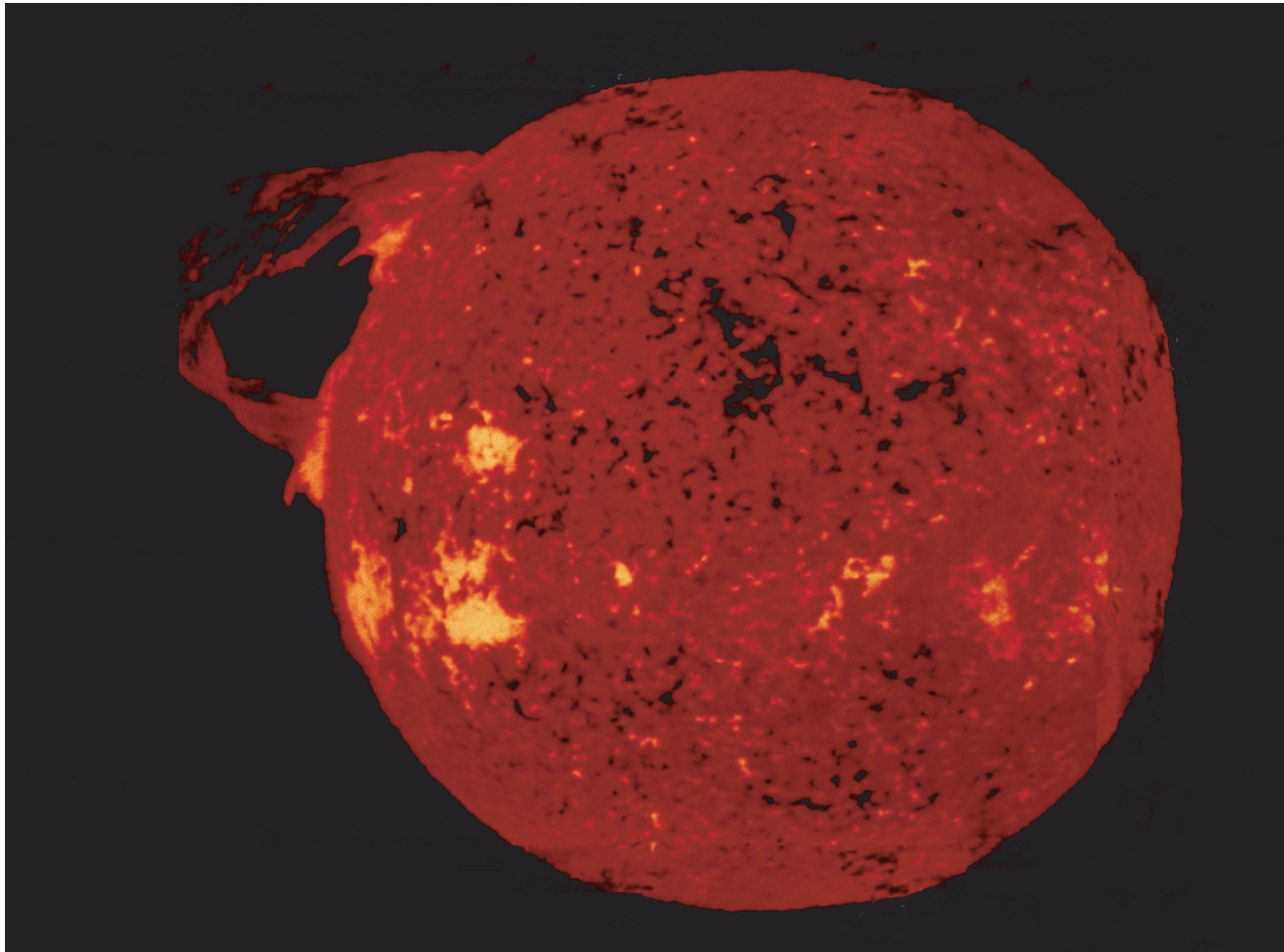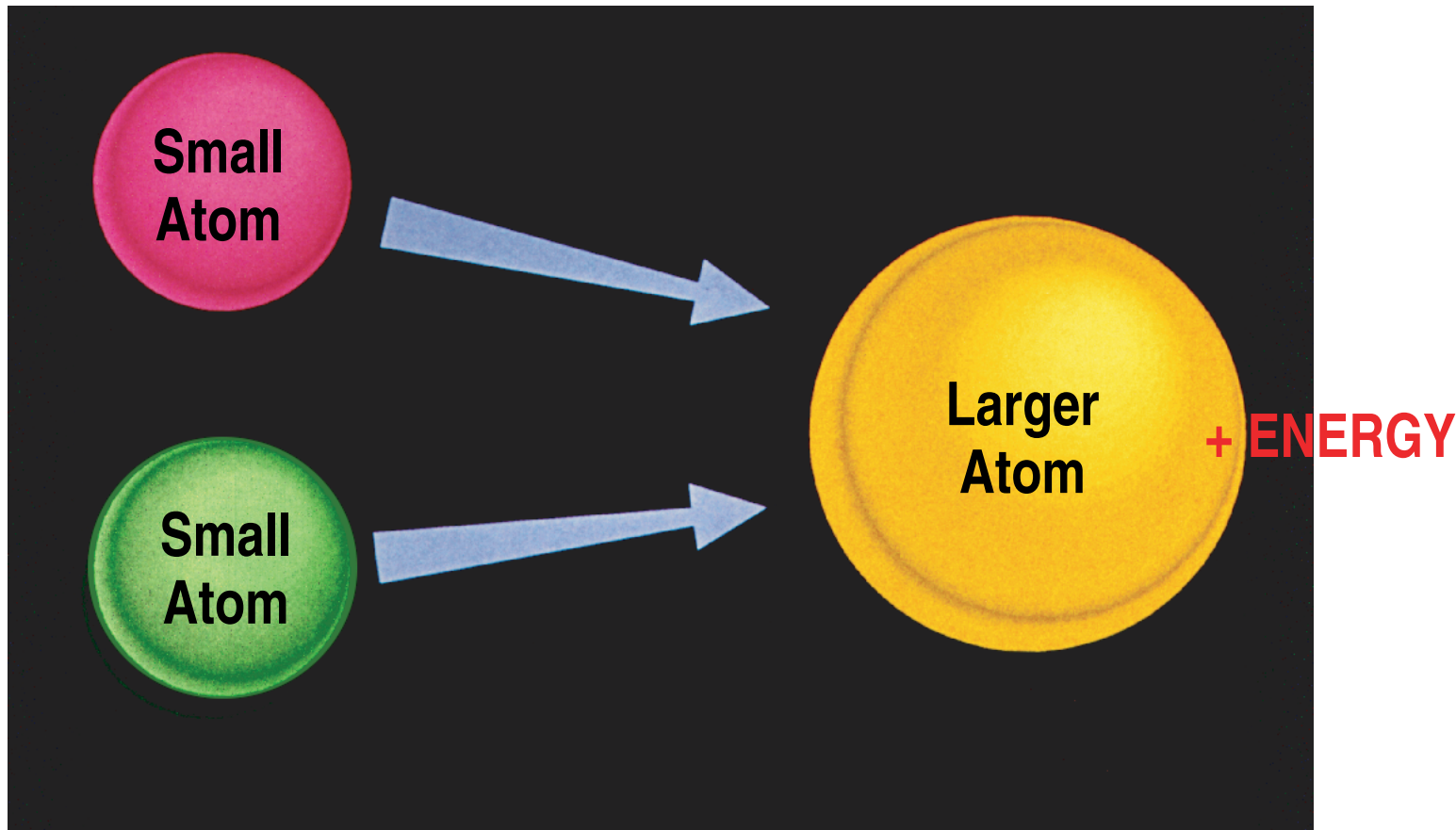
COMMERCIAL NUCLEAR PLANTS ARE FISSION REACTORS

Fission: A large atom is split into two smaller atoms

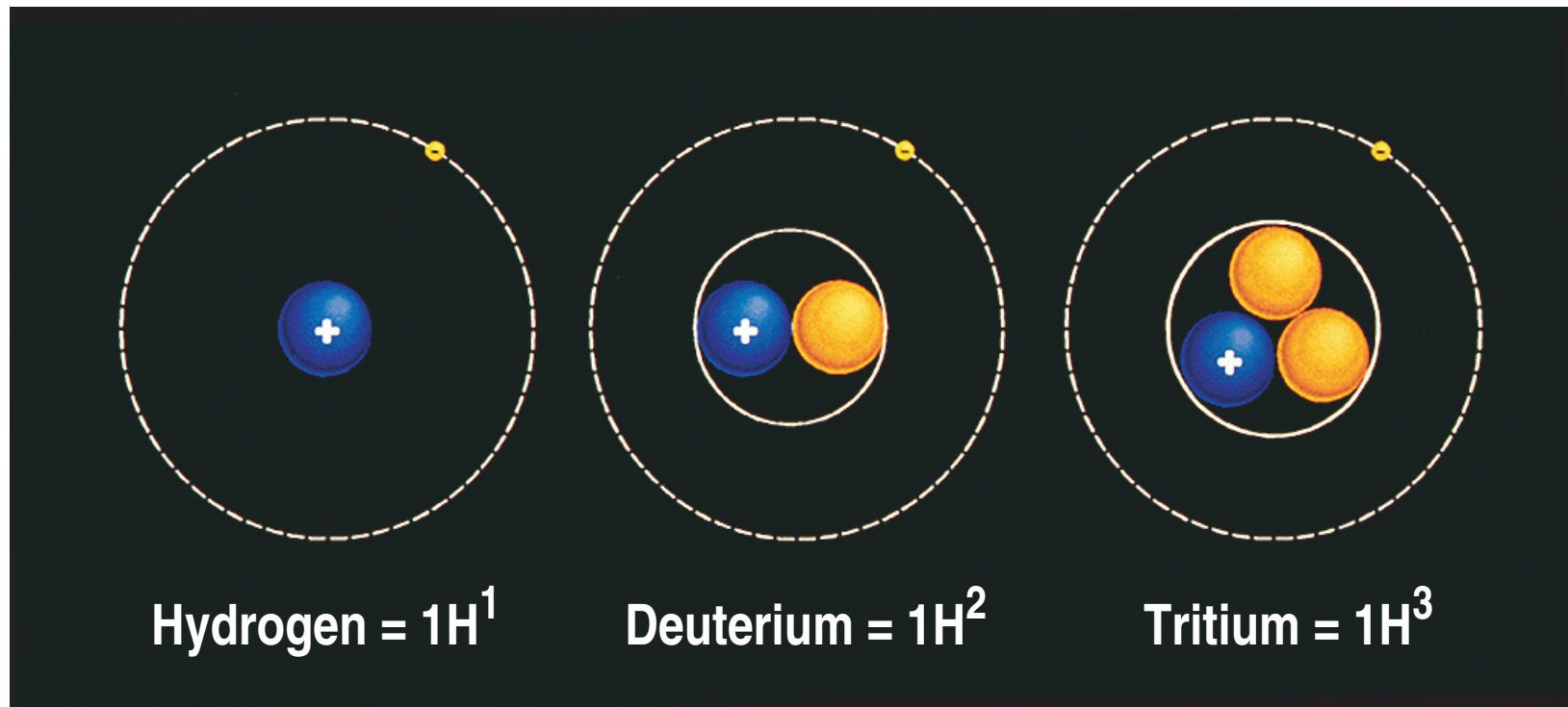# FUSION: COMBINING TWO LIGHT ATOMS INTO ONE HEAVIER

ISOTOPES OF HYDROGEN ARE THE FUEL OF FUSION

- **Like charges repel thus joining two positively charged nuclei requires work**

- **High temperatures required for fusion rip the electrons from the atom**
  - **Plasma is an ionized gas, a sea of positively charged ions and electrons**

Hydrogen = $1H^1$ Deuterium = $1H^2$ Tritium = $1H^3$

IN FUSION NUCLEAR MASS IS CONVERTD INTO ENERGY

- **Fraction of mass "lost" is small, just 38 parts out of 10,000**

- **1 gram of DT equals the energy from 2,400 gallons of oil**

$$E=mc^2$$
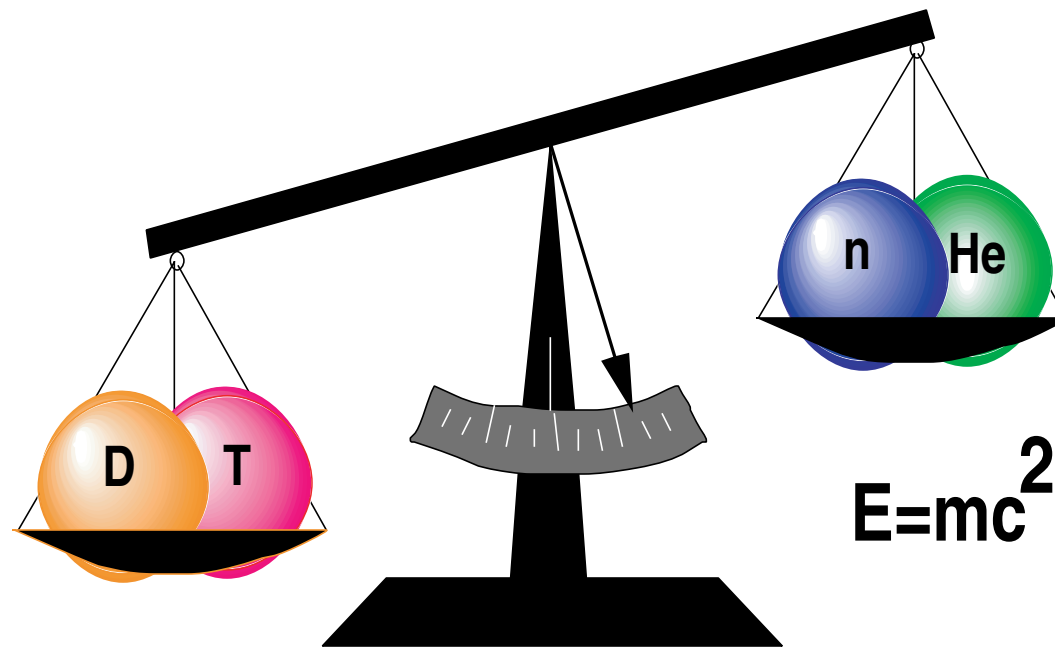
FUSION REPRESENTS AN INEXHAUSTIBLE ENERGY SOURCE

● **Fusion fuel is very energy dense**

Coal — ~2,000,000 Tonnes (21,010 Railcar Loads)

Oil — ~1,300,000 Tonnes (10,000,000 Barrels)

Fission — ~30 Tonnes UO2 (One Railcar Load)

Fusion — ~0.6 Tonnes D (One Pickup Truck)

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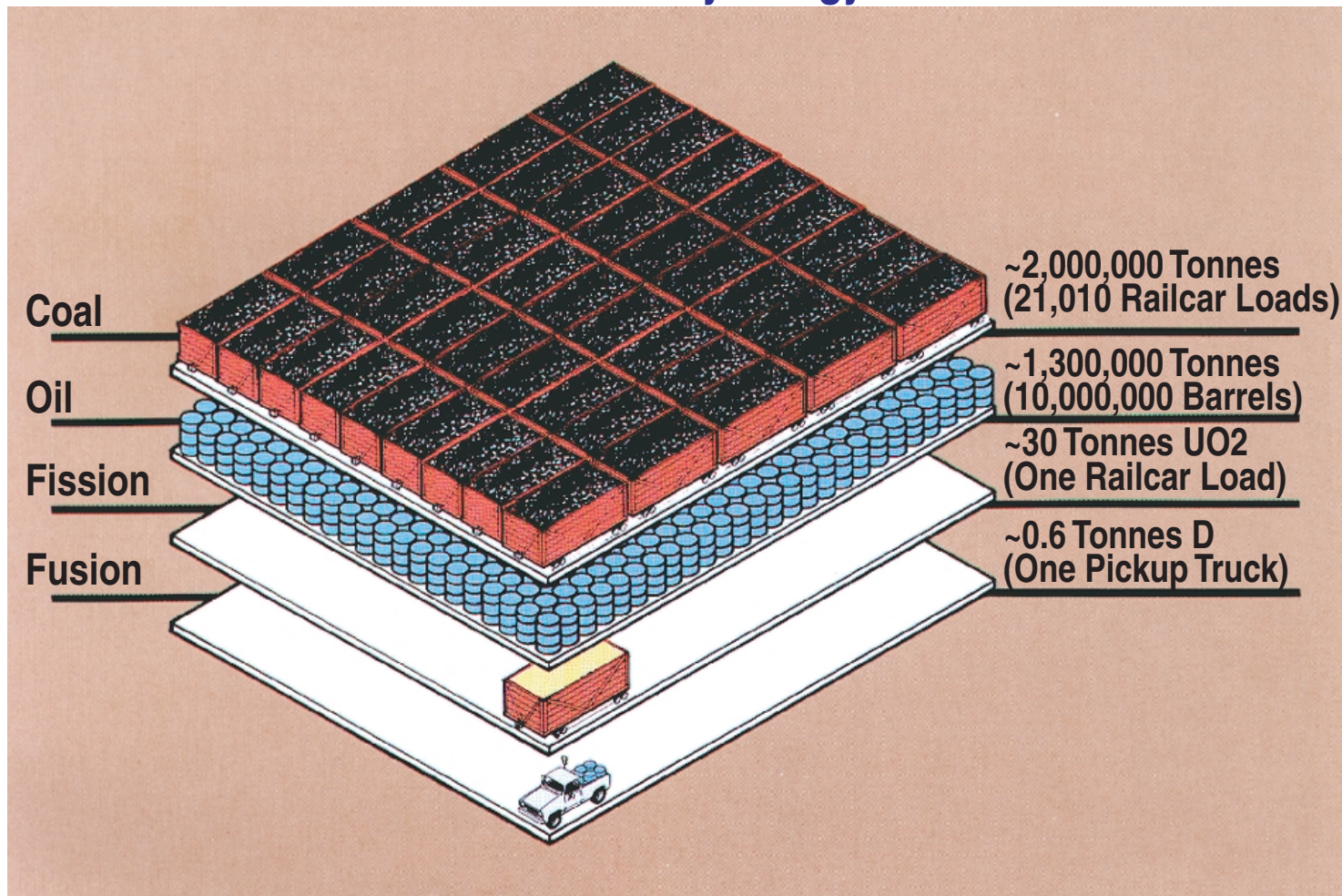
MAGNETIC FIELDS CAN CONFINE A VERY HOT FUSION PLASMA

- **Charged particles follow magnetic field lines**

Unconfined

Confined

Ion

Electrons

Magnetic
Field Lines

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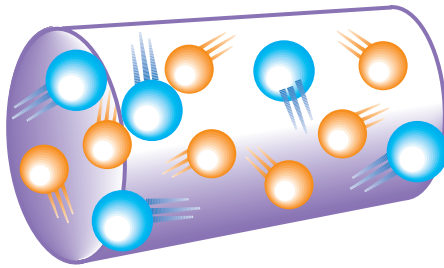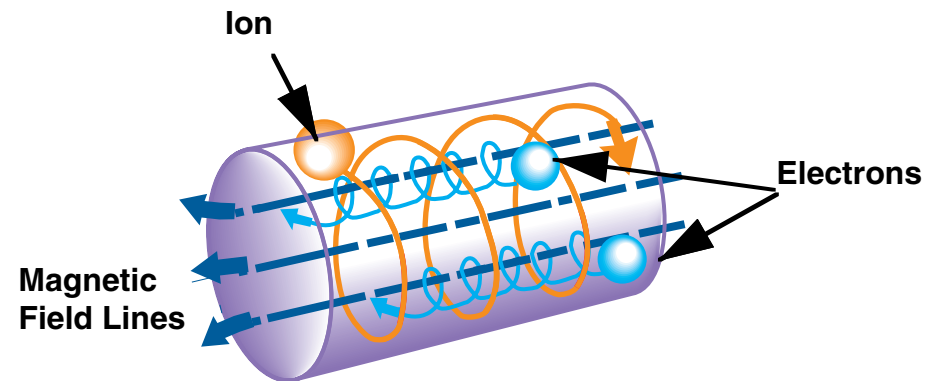
TOROIDAL MAGNETIC CONFINEMENT OF PLASMA

- **Fusion plasmas are 100,000,000 degrees C**

Tokamak Confinement
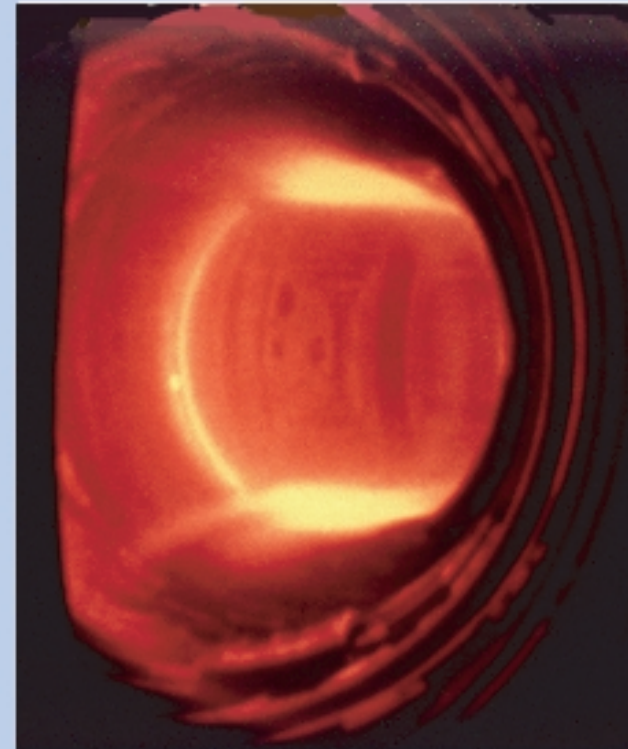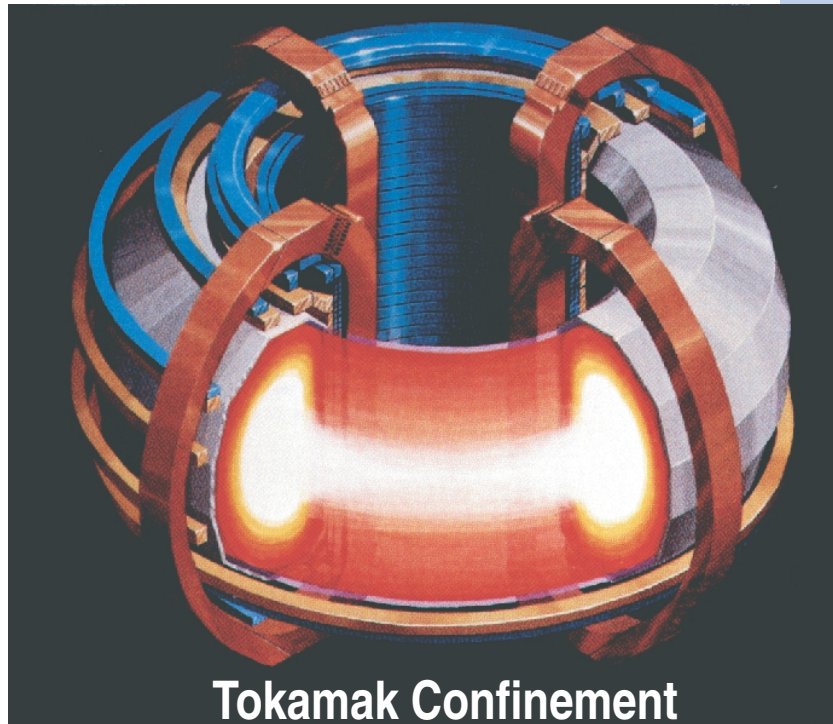
Picture of a Tokamak Plasma

THREE LARGE TOKAMAK EXPERIMENTS IN THE UNITED STATES

● **Approximate $1 Billion replacement cost**
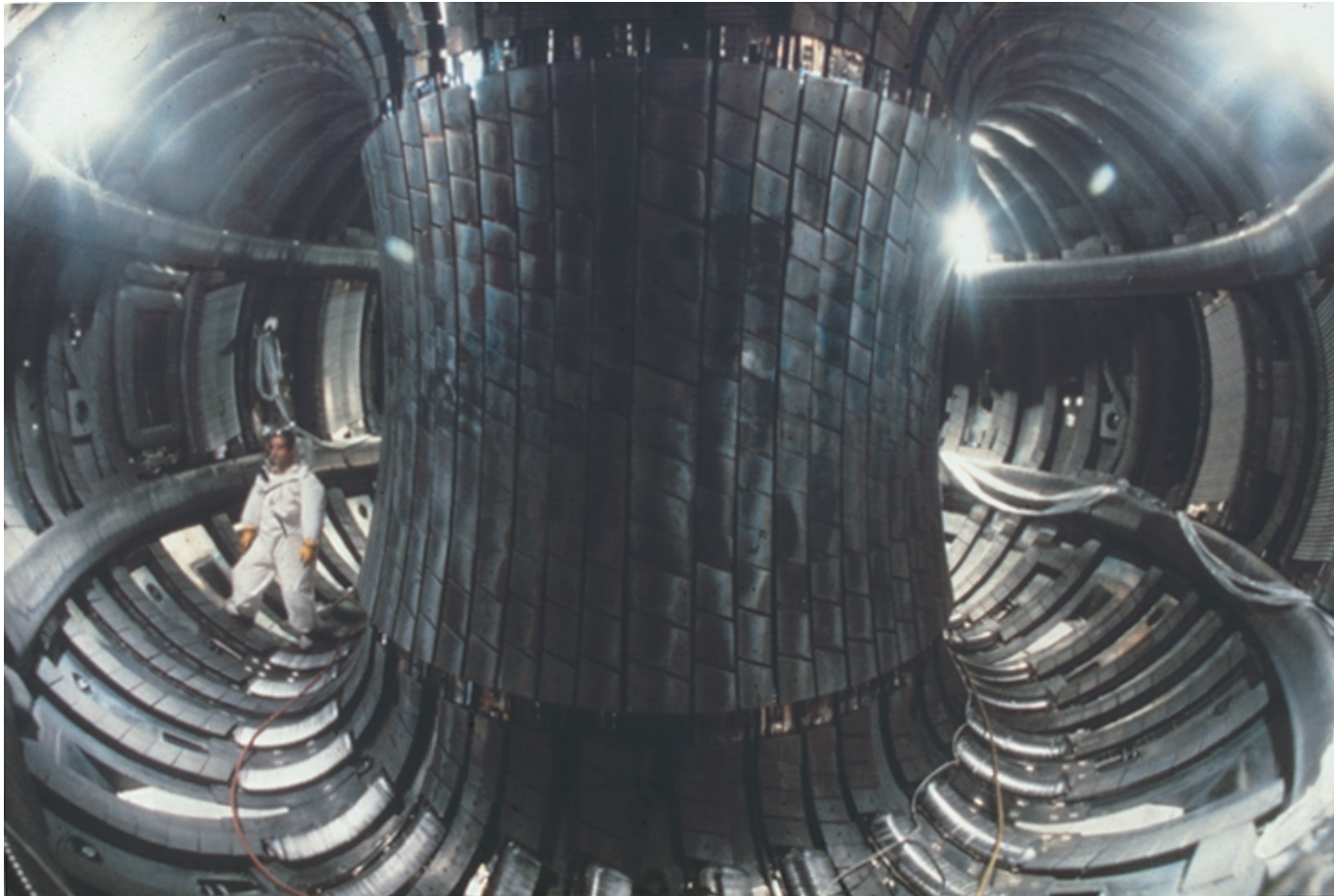
THE COLLABORATORY WILL EMBRACE 40 US SITES IN 37 STATES

Fusion Collaboratory

Legend:
- ● Fusion Research Center
- ★ Large Fusion Experiment
- ▲ CSET Partner
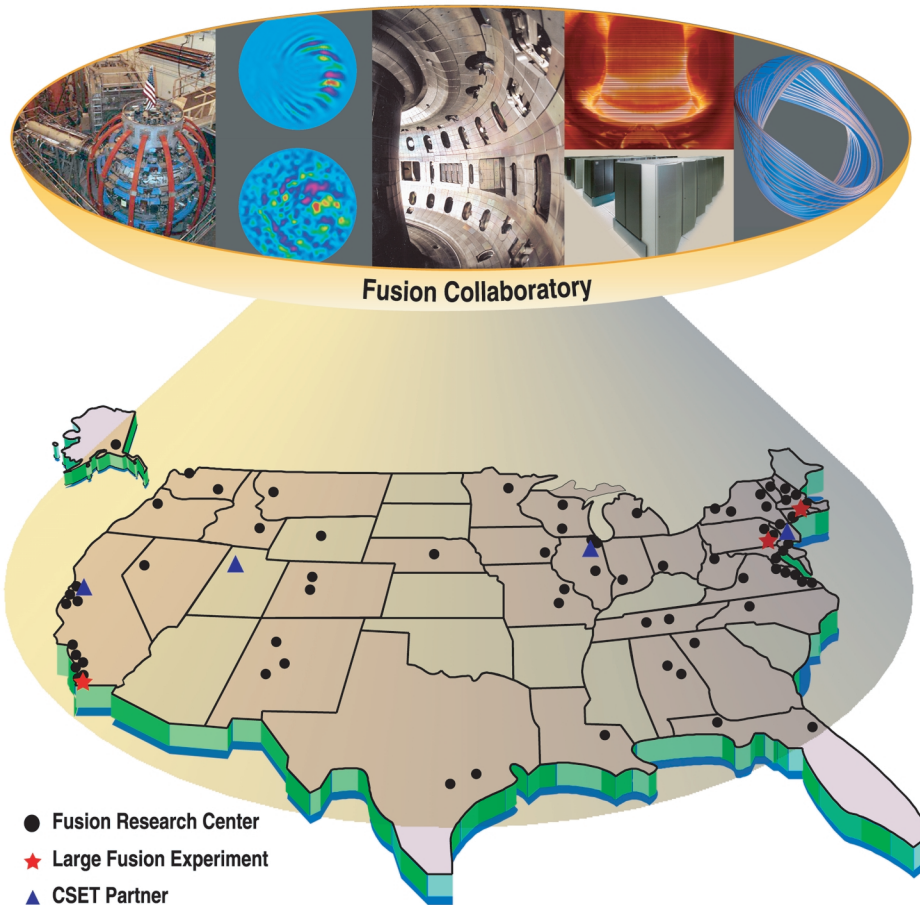
- **The Collaboratory will be created by a diverse team**
  - **3 large fusion experiments**
    - ✳ **C–Mod, DIII–D, NSTX**
  - **4 computer science centers**
    - ✳ **ANL, LBNL, Princeton U., U. of Utah**

- **Coordinated with the user community**
  - **Main experimental sites**
  - **Theory & simulation community**

- **A 3 year effort costing $5.4 million**
  - **2/3 CSET and 1/3 Fusion**
  - **For software, not hardware**

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THE GOAL OF THE FUSION COLLABORATORY IS TO ADVANCE SCIENTIFIC UNDERSTANDING & INNOVATION IN FUSION RESEARCH

- Enable more efficient use of existing experimental facilities through more powerful between pulse data analysis resulting in a greater number of experiments at less cost

- Allowing more transparent access to analysis and simulation codes, data, and visualization tools, resulting in more researchers having access to more resources

- Enable more effective integration of experiment, theory, and modeling

- Facilitate multi–institution collaborations

- Create a standard tool set for remote data access, security, and visualization allowing more researchers to build these services into their tools

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THE COLLABORATORY WILL CREATE & DEPLOY COLLABORATIVE SOFTWARE TOOLS FOR THE FUSION COMMUNITY

- **Create transparent and secure access to local/remote computation, visualization, and data servers**

- **Develop collaborative visualization that allows interactive sharing of graphical images among control room display devices, meeting room displays, and with offices over a wide area network**

- **Enable real–time access to high–powered remote computational services allowing such capabilities as between pulse analysis of experimental data and advanced scientific simulations**

EXAMPLE OF COLLABORATORY BENEFITS:
ENHANCED EXPERIMENTAL OPERATIONS

Work Flow

① Data Retrieval

② Computation

③ Data Storage

④ Visualization

⑤ Shared Visualization

⑥ Adjusted DIII–D Pulse

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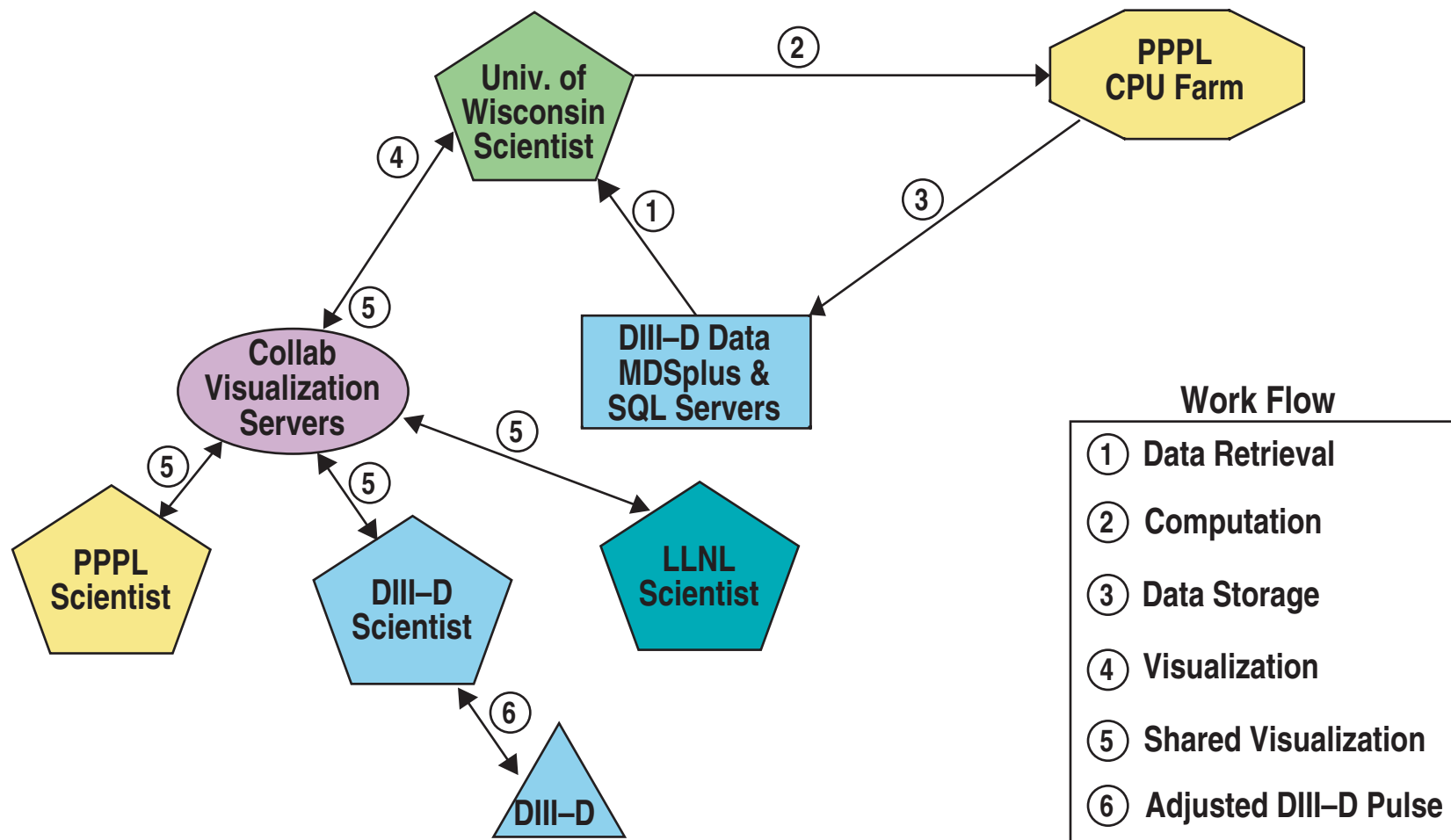
EXAMPLE OF COLLABORATORY BENEFITS:
REMOTE DATA ACCESS AND DISPLAY

Visualization Server

GSI Authentication Servers

①

Columbia Univ. Scientist

③ Columbia CPU

② DIII–D Data MDSplus & SQL Servers

② NSTX Data MDSplus & SQL Servers

④

⑤

Columbia Scientist ⑤ 3D Visualization Server ⑤ DIII–D Scientist

⑤

NSTX Scientist

Work Flow

① Authentication

② Data Retrieval

③ Computation

④ Visualization

⑤ 3D Visualization

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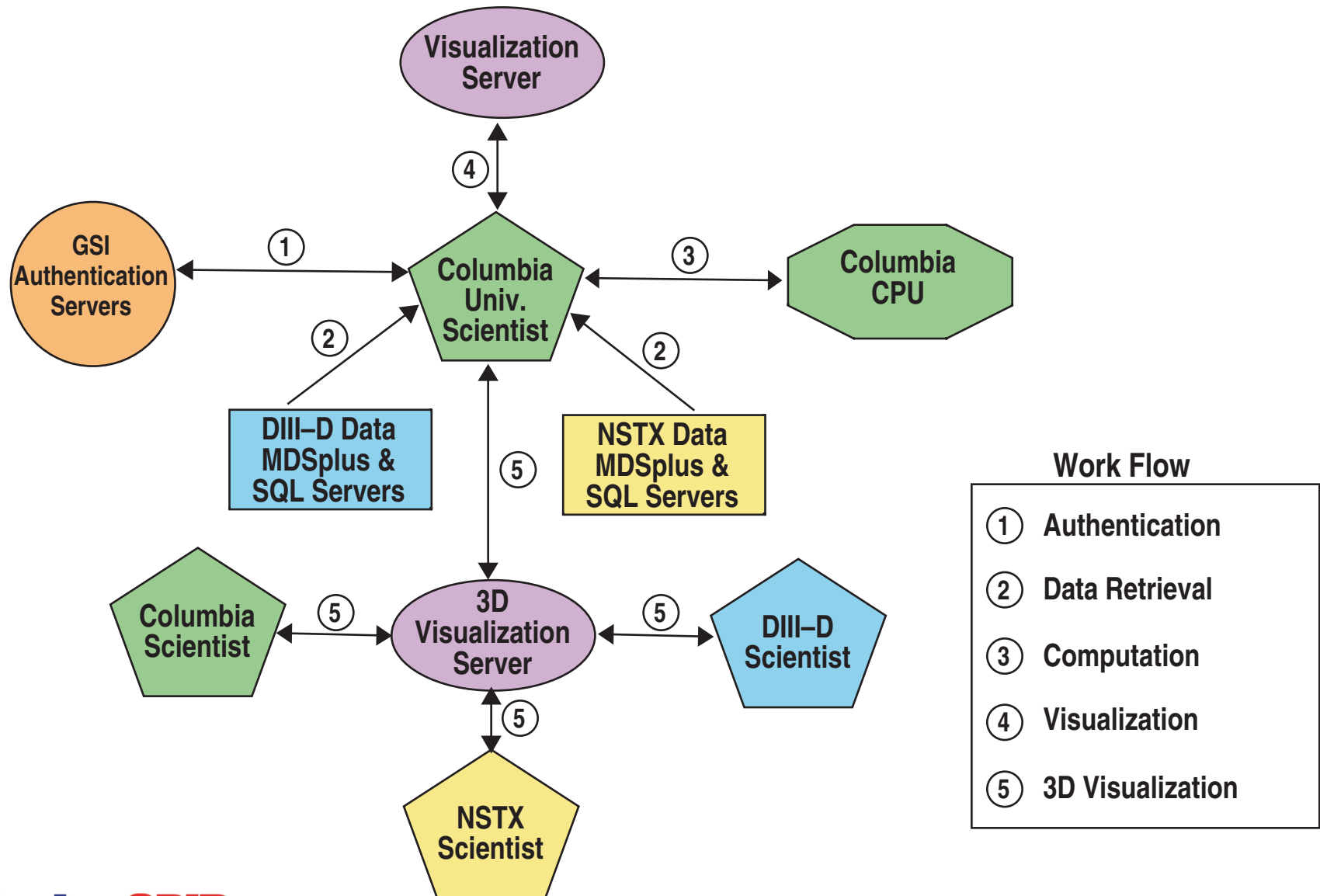
EXAMPLE OF COLLABORATORY BENEFITS:
REMOTE AND DISTRIBUTED DATA ANALYSIS

Work Flow

1. Data Retrieval
2. Computation
3. Data Storage
4. MPP Computation
5. Authorization
6. Data Storage

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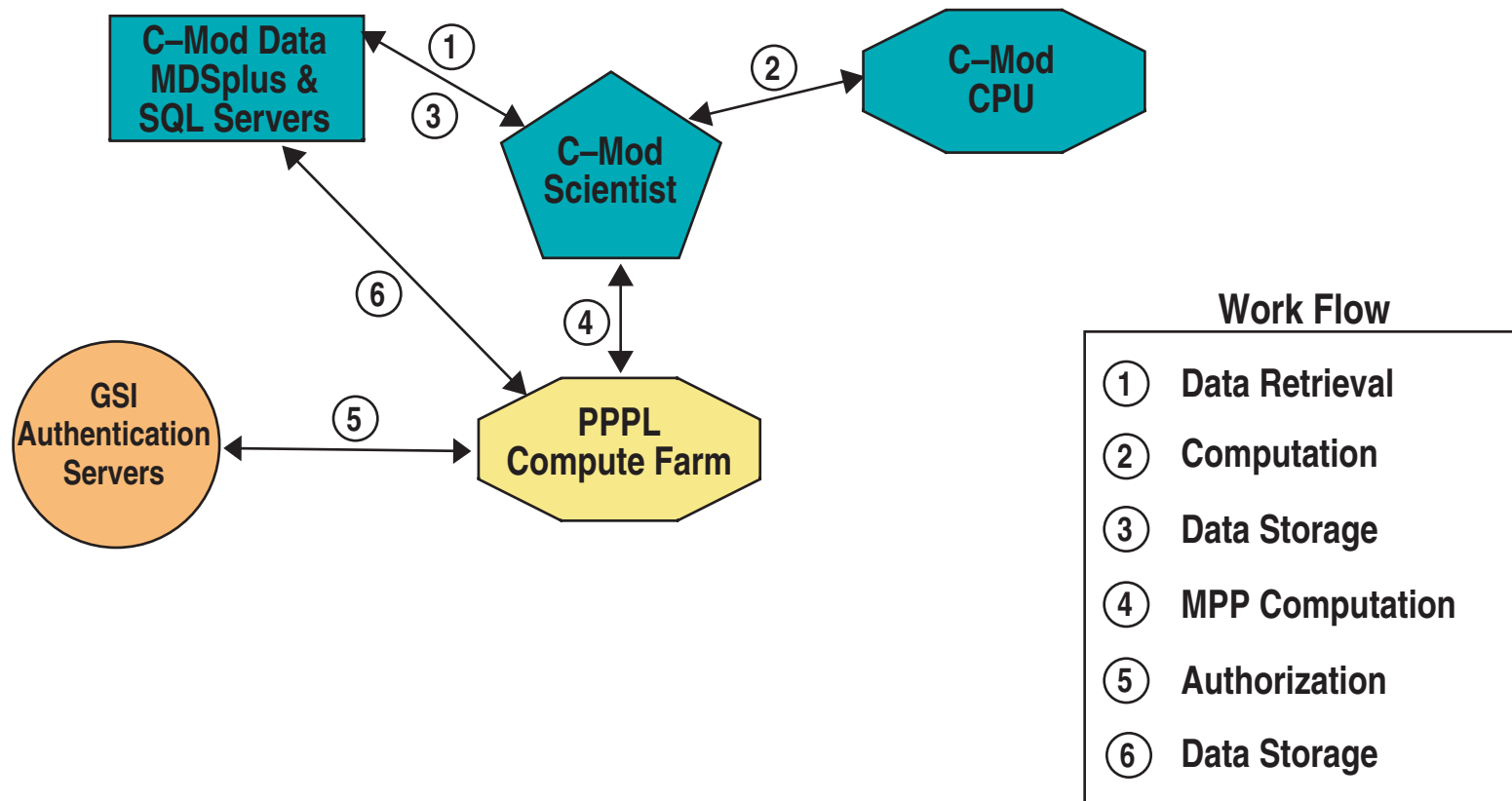
EXAMPLE OF COLLABORATORY BENEFITS:
COMPARISON BETWEEN SIMULATION AND EXPERIMENT

LLNL Scientist

MPP Compute Farm

C-Mod Data MDSplus & SQL Servers

LLNL CPU

DIII–D Data MDSplus & SQL Servers

3D Visualization Server

Work Flow

① MPP Computation

② Data Storage

③ Synthetic Diagnostic

④ Data Retrieval

⑤ Visualization

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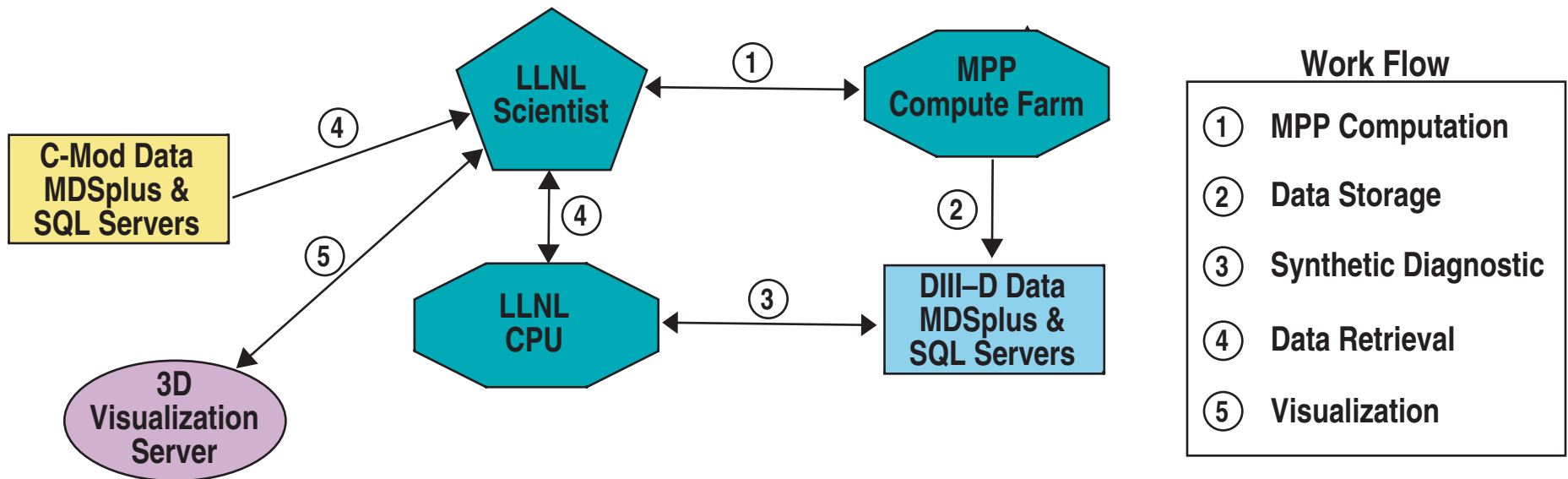
MDSplus PROVIDES A COMMON, SHARED NETWORK ENABLED INTERFACE TO ALL DATA

- **MDSplus is a data system jointly developed by MIT, LANL, & Padova Italy**

  - **Provides for acquisition, storage, access, and organization of data**

  - **Client/server system utilizing TCP/IP**

  - **Can store experimental, simulation & theoretical data**

- **Presently used to serve data at 4 sites in US and 8 worldwide**

  - **Includes the 3 large US tokamaks**

  - **Clients at many sites**

- **Many physics analysis codes have been or are being integrated with MDSplus**

  - **Transport: MIST, ONETWO, TRANSP**

  - **MacroStability & Equilibrium: DCON, EFIT, M3D, NIMROD, PEST**

  - **MicroTurbulence: GS2**

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MDSplus CHARACTERISTICS

- **Hierarchical and self descriptive**

- **Supports a variety of primitive data types**
  - Byte, word, long, float, double, complex, string, expressions, actions
  - Built in expression evaluator (TDI)

- **Remote access available currently from**
  - Fortran, C/C++, Java, Python, IDL, Matlab, and labview

- **Tools exist for quick display of data and structure**
  - X–windows and Java scope & traverser
  - IDL tools (ReviewPlus, Pslice, JETDSP, etc.)
  - Matlab tools

- **Supported platforms (so far)**
  - AIX, Cray Unix, Digital Unix, HP/UX, Irix, Linux, Mac OS, Sun OS, VMS, Win32 (windows 9x, NT, 2000)

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MDSplus WILL UNIFY DATA ACCESS FOR THE THEORETICAL COMMUNITY JUST AS IT HAS FOR THE EXPERIMENTAL COMMUNITY

Conventional Storage
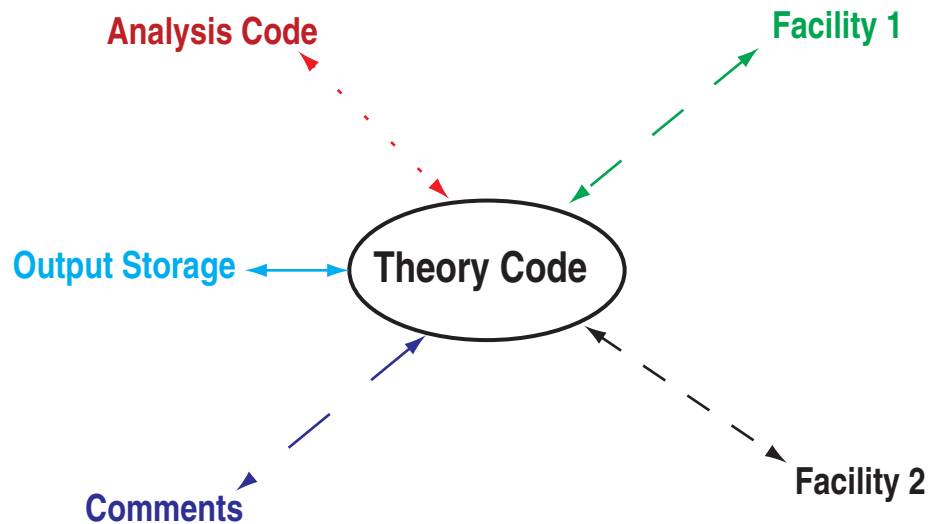
- **Each code needs it own interface**
- **Must know data format and file location**
- **Each code has its own graphics tool**
- **Hard to share results**

MDSplus
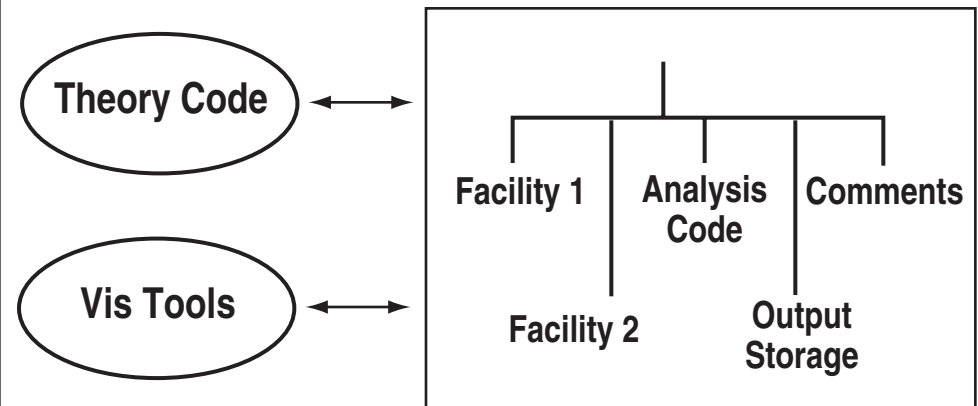
- **One interface to many data types**
- **Only need location of data in tree**
- **Utilize existing visualization tools**
- **Easy to share results with both the theoretical and experimental community**

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A RELATIONAL DATABASE WORKS IN CONCERT WITH MDSplus

- **MDSplus stores or is a gateway to all the data**
  - Not optimized for queries across multiple pulses

- **Relational DB stores highlights of the data**
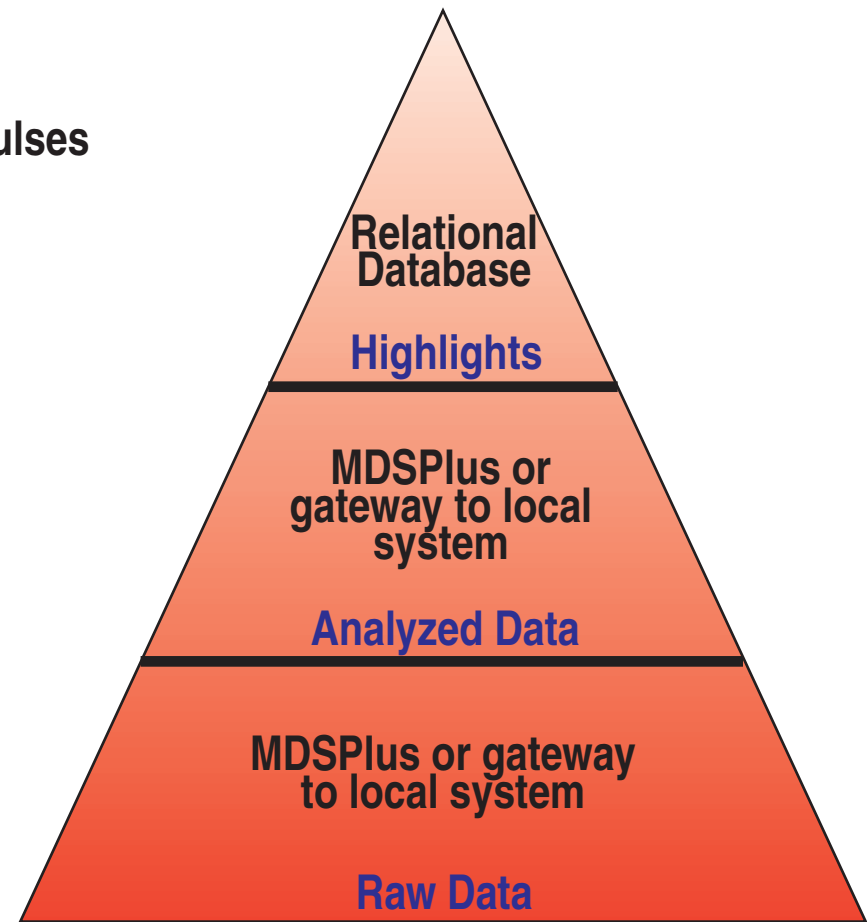 - Optimized for queries
  - Drill down to smaller dataset

- **Requirements of relational DB**
  - Archival storage of data highlights
  - Track code runs
  - Interface to visualization software
  - Flexible schema evolution
  - Transparent access across WAN

Relational
Database

Highlights

MDSPlus or
gateway to local
system

Analyzed Data

MDSPlus or gateway
to local system

Raw Data

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COMPARISON OF NIMROD SIMULATION TO
DIII–D EXPERIMENTAL DATA IS FACILITATED WITH MDSplus

- **NIMROD P_e overlayed onto DIII–D measurement**
  - **Synthetic diagnostics**

- **NIMROD data in MDSplus**
  - **Widely accessible**

- **Data easily accessible to visualization tools**
  - **These plots with IDL**

86144.02500

DIII–D Experiment

NIMROD Simulation

Z (m)

Normalized Pressure
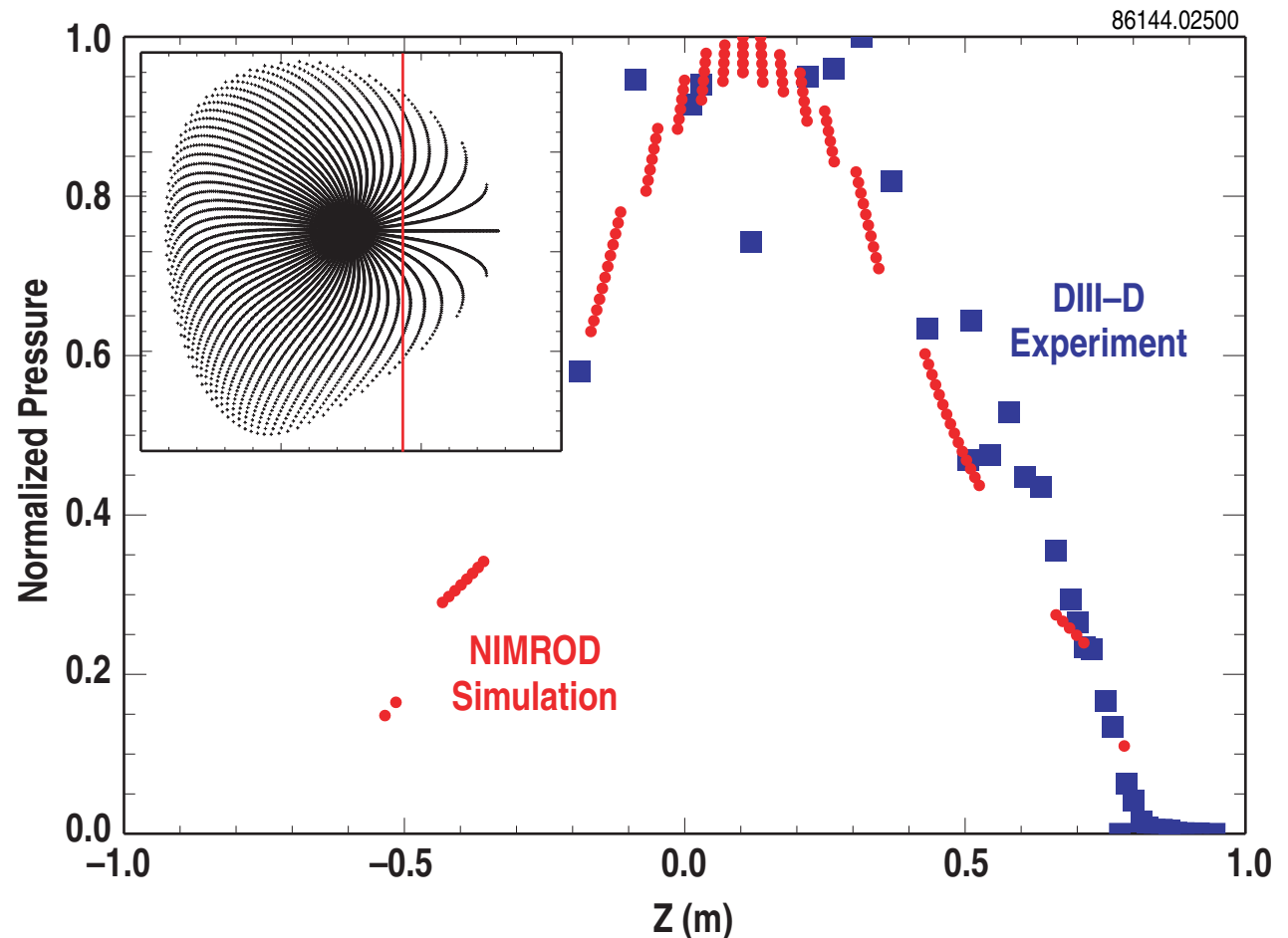
- **With MDSplus the data is easy to retrieve & the plot is easy to create**
  - **This work performed for the PSACI Macrostability group**

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THE COMPUTER SCIENCE RESEARCH NECESSARY TO CREATE THE COLLABORATORY IS CENTERED AROUND THREE AREAS

- **Security**

  - Valuable resources need to be protected: data, codes, & vis tools

  - Collaboratory will require authentication, authorization, and encryption

  - Fair use of shared resources

- **Remote and Distributed Computing**

  - Share the community's computational resources

  - Job scheduling, monitoring, exception handling, and accounting

- **Scientific Visualization**

  - Increased data quantities and ease of collaboration requires better visualization technology

  - Collaborative control rooms & meeting rooms, and enhanced vis tools

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SECURITY: THE COLLABORATORY WILL UTILIZE THE GLOBUS SECURITY INFRASTRUCTURE & AKENTI AUTHORIZATION SERVICE

- Globus (www.globus.org) is a research and development project focused on enabling the application of Grid concepts to scientific computing

- The Grid refers to an infrastructure that enables the integrated, collaborative use of high–end computers, networks, databases, and scientific instruments owned and managed by multiple organizations

- Akenti (www-itg.lbl.gov/Akenti/) is an access control system designed to address the issues raised in allowing restricted access to distributed resources which are controlled by multiple organizations

- Existing fusion codes will be modified to use this infrastructure

- The middleware tools will be extended to meet Collaboratory needs

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SECURITY: THE COLLABORATORY WILL UTILIZE THE GLOBUS SECURITY INFRASTRUCTURE & AKENTI AUTHORIZATION SERVICE

- **Globus is an R&D project for grid based scientific computing**
  - **Collaborative use of computers, network, & data from multiple organizations**

- **Akenti is an R&D project for access control**
  - **Restricted access to distributed resources controlled by multiple organizations**

- **Fusion codes will be modified to use this infrastructure**

- **The middleware tools will be extended to meet collaboratory needs**
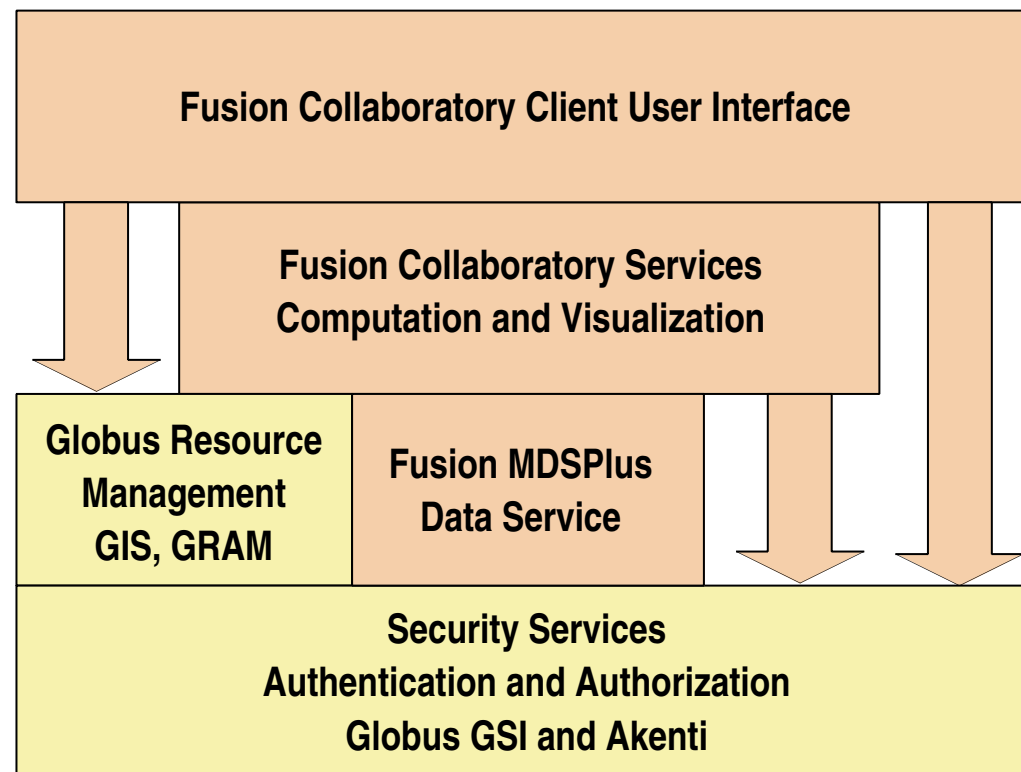

S. S. Mudumbai, et al.

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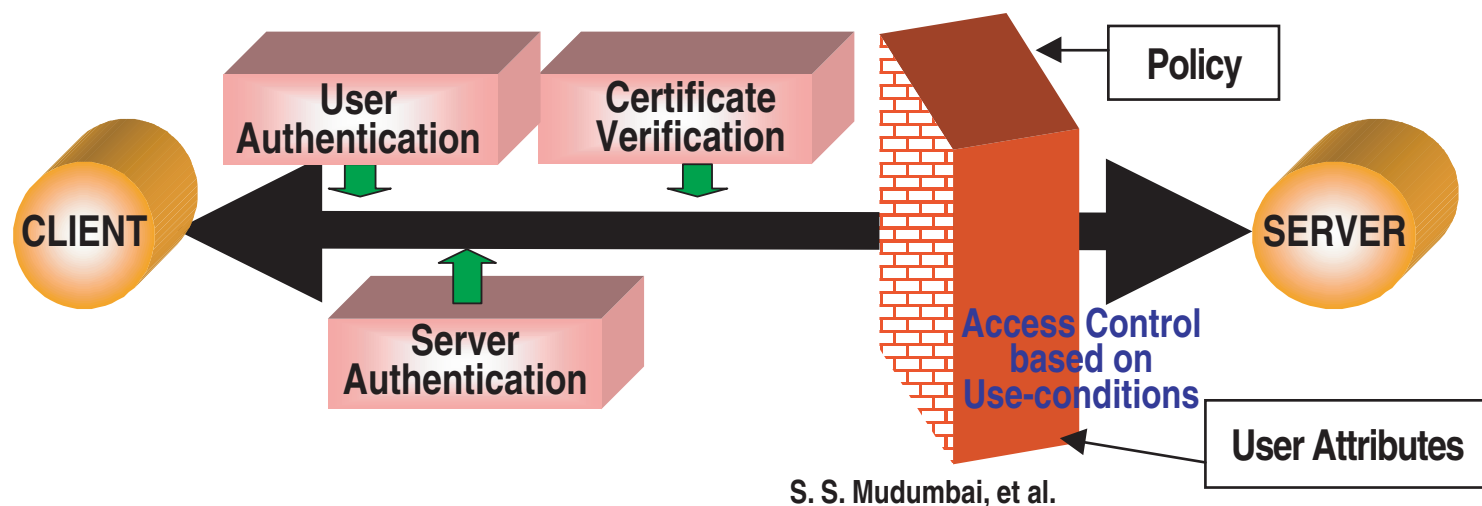
REMOTE & DISTRIBUTED COMPUTING: ACCESS TO POWERFUL DATA ANALYSIS & SIMULATION CODES AS NETWORK SERVICES

- **Fusion codes will run on hardware appropriate for each code**
  - Fast serial workstations – midrange parallel clusters – supercomputers

- **Collaboratory will enable detailed time dependent transport and stability analysis between pulses**
  - Equitable sharing and preemptive data analysis

- **Globus can provide for the required capabilities**
  - Create grids connecting computational resources with users
  - Track the capabilities of resources within a grid
  - Specify the resource needs of user's computing tasks
  - Mutually authenticate both users and resources

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SERVICES ARE LAYERED TO HIDE COMPLEXITY WHILE PROVIDING POWERFUL TOOLKITS FOR DEVELOPERS

- **MDSplus will provide the common data access for the Collaboratory**

- **Globus and Akenti will provide the necessary middleware**

Fusion Collaboratory Client User Interface

**Fusion Collaboratory Services
Computation and Visualization**

Globus Resource Management GIS, GRAM

Fusion MDSPlus Data Service

**Security Services
Authentication and Authorization
Globus GSI and Akenti**

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# VISUALIZATION: COLLABORATIVE NATURE OF FUSION RESEARCH NECESSITATES A SHARED VISUALIZATION ENVIRONMENT

- **Strive to dramatically reduce the hurdles that presently exist for collaborative visualization**

- **Leverage existing technology where possible**
  - **Workspace docking using the Access Grid (AG)**
  - **Integrate existing AG collaborative tools with tiled display walls**

- **Collaborative Control Room**
  - **Large on–site group to interactively work with small to large off–site group**

- **New visualization software**
  - **Simultaneous sharing of complex visualizations**
  - **Error representation in complex experimental and simulation data**

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TILED DISPLAYS WALLS ALLOW A LARGE GROUP OF SCIENTISTS TO EXPLORE INFORMATION IN COLLABORATION MORE EFFECTIVELY

- **Access Grid (www.accessgrid.org) compliments and extends the data grid**
  - **Ensemble of network, computing and interaction resources that supports group to group collaboration and communication**

- **Display wall research has focused on low–cost commodity components**
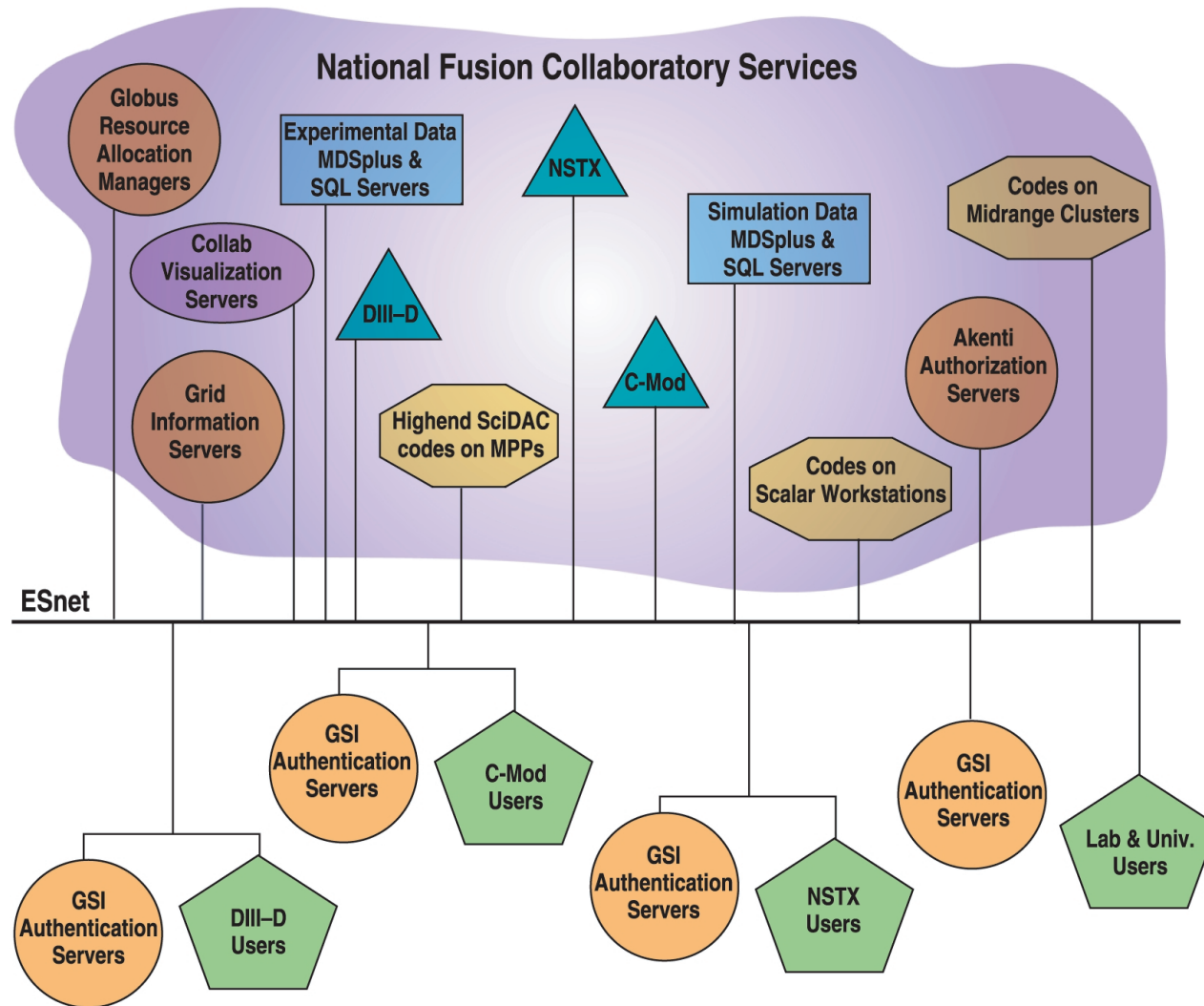
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VISUALIZATION TOOLS WILL BE CREATED THAT REPRESENT A SIGNIFICANT INCREASE IN EFFICIENCY FOR THE FUSION COMMUNITY
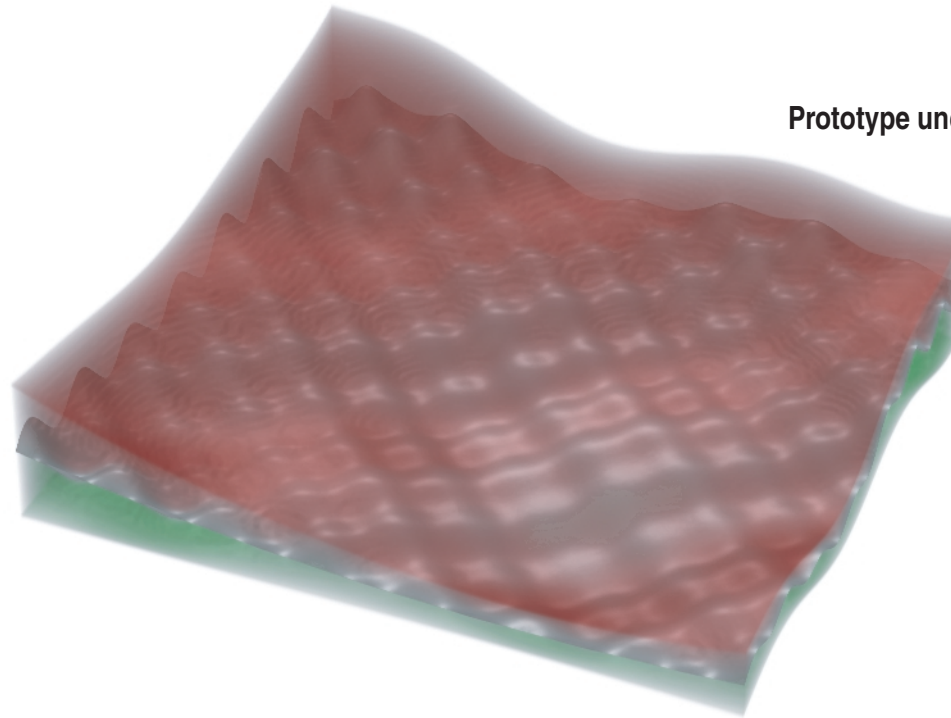
Prototype uncertainty visualization
courtesy U. of Utah

- Provide visualizations that incorporate and compare data from multiple experimental and simulation sources and to reflect uncertainty information to aid in data analysis

- Collaborative visualization tool will be created for experimental operations giving both local and remote teams an interactive, big picture view of the vast amount of data

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CREATE A UNIFIED FRAMEWORK SO DATA, CODES, VIS TOOLS ARE AVAILABLE SECURELY & TRANSPARENTLY OVER THE INTERNET

National Fusion Collaboratory Services

Globus Resource Allocation Managers

Experimental Data MDSplus & SQL Servers

NSTX

Collab Visualization Servers

DIII–D

Simulation Data MDSplus & SQL Servers

Codes on Midrange Clusters

Grid Information Servers

Highend SciDAC codes on MPPs

C-Mod

Akenti Authorization Servers

Codes on Scalar Workstations

ESnet

GSI Authentication Servers

C-Mod Users

GSI Authentication Servers

GSI Authentication Servers

GSI Authentication Servers

Lab & Univ. Users

GSI Authentication Servers

DIII–D Users

NSTX Users

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SUMMARY

- **A 3–year project to create a Fusion Collaboratory has begun**

- **Team effort comprised of fusion scientists and computer scientists**

- **The collaboratory will enable networked real–time data analysis and instantaneous communication amongst geographically dispersed teams of experimentalists and theoreticians**

- **The goal of the Collaboratory is to advance scientific understanding and innovation in fusion research**

- **More information at http://www.fusiongrid.org/**